RETARDATION OF COMBUSTION ON PASSING THROUGH WIRE SCREENS IN CLOSED PIPE

BY

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A STUDY OF THE RETARDATION OF COMBUSTION ON PASSING THRU WIRE SCREENS PLACED IN A CLOSED PIPE.

A

THESIS

Presented by

E. Wallace McDiarmid

To the

PRESIDENT

and

Members of the Faculty

of

THE ARMOUR INSTITUTE OF TECHNOLOGY

For the degree of

Bachelor of Science

in

FIRE PROTECTION ENGINEERING

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E. Wallace McDiarmid.

Chicago, Illinois

May 1916.

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A Study of the retardation of combustion in passing thru wire screens placed in a closed pipe.

The subject matter of this thesis is divided into five parts:-

Part one,

Introduction and statement of trade customs in the manufacture of wire screens;

Part two,

A statement of the problem;

Part three,

Description of apparatus;
a.General.
b.Method of inserting screens.
c.Thermo-couple flame detectors.
d.Relief valves.

Part four,

Description of tests;
Data.

Part five,

A restatement of problem and discussion of the variable factors.

Part one.

The first person to employ the known phenomenon, that combustion will not pass thru the mesh of fine wire screens, was Sir Humphry Davy. The Davy lamp consists essentially of a wire screen cylinder surrounding the flame of an ordinary miners lamp. The gas passes thru the meshes to supply the flame but the flame does not flash out thru the meshes when in the presence of explosive mixtures of gas and air. The presence of this mixture is detected by the sputtering of the lamp. Close observation will show tiny flames just inside the screen but die out before passing thru the mesh. The cooling properties of the wire screen cool the flame below the kindling point and hence dies. The limiting size of the openings and the size of wire have not been determined.

The mere statement of the mesh of a wire screen will not identify it. There are certain customs observed in this industry which

I will quote from the catalogue of the Clinton Wire Cloth Company, Clinton, Massachusetts.

Terms and Customs of the Wire Cloth Industry.

Warp and Filling — Warp wires are those which run longitudinally in the cloth. Filling wires run transversely in the cloth and cross alternately over and under the warp wires. In describing cloth the warp mesh and wire precede, in their respective positions, the same elements of the filling. Thus 9 x 8 mesh No18/19 wire indicates that the warp has 9 meshes per lineal inch and is made from No18 wire; and the filling has 8 meshes per lineal inch and is made from No.19 wire.

Mesh — The size of any mesh in wire cloth is the distance from the center to center of its parallel wires - not the clear space between these wires. The numeral which precedes this word in the description of the cloth indicates the number of openings it has in one lineal inch.

Thus 4 mesh means that the cloth has 4 openings per lineal inch, each measuring 1/4" from center to center of its parallel wires.

The clear space between the wires id determined by the size of the wire used in the cloth and is found by deducting the diameter of one of its wires from the size of the mesh. Thus, if No.16 steel wire (which is 1/16" diameter) were woven into 4 mesh cloth, it would show 3/16 inch clear space, or 1/4 inch (size of mesh) less 1/16 inch (diameter of wire).

The filling meshes in many of the very fine grades, and also in some of the medium ones made from the largest wire that can be woven in each, are somewhat larger than the warp meshes because it is impossible to force wire beyond a certain point without straining it and impairing its efficiency.

Space

This term, or as it is sometimes expressed "hole" or "opening", means clear space between adjacent wires, and

its size is not affected by the diameter of the wire used in the cloth. Thus, cloth of 1/4 inch space will allow material 1/4 inch in diameter to pass thru it regardless of the size of wire from which it is woven.

Wire Gauges

The recognized standards for gauging wire fabrics are the Washburn and Moen gauge for Iron, Steel, Galvanized, Tinned and Coppered wire, and Old English gauge for Brass, Copper and Bronze wire. The diameters of all sizes of these standards, expressed in decimals of an inch, are shown below.

It is recommended that the micrometer caliper for gauging all kinds of wire, because it insures greater accuracy, even in the hands of a novice, than does a V or a circular gauge when used by an expert.

In all kinds of commercial wire there is a slight variation which is more frequently over than under the diameter specified by the standard under which it is classified; and in

weaving fine sizes, particularly of soft metals, the tension to which they are subjected in the loom tends to elongate them and thus slightly reduces their diameters.

COMPARISON OF VARIOUS METAL GAUGES.

No.of Gauge	Washburn & Moen	Old English	U. S. Stand.	American	No.of Gauge
20	.0348	.0350	.0375	.0320	20
21	.0317	.0315	.0344	.0285	21
22	.0286	.0295	.0313	.0253	22
23	.0258	.0270	.0281	.0226	23
24	.0230	.0250	.0250	.0201	24
25	.0204	.0230	.0219	.0179	25
26	.0181	.0205	.0188	.0159	26
27	.0173	.0187	.0172	.0142	27
28	.0162	.0165	.0156	.0126	28
29	.0150	.0155	.0141	.0113	29
30	.0140	.0137	.0125	.0100	30
31	.0132	.0122	.0109	.0089	31
32	.0128	.0112	.0102	.0080	32
33	.0110	.0102	.0094	.0071	33
34	.0100	.0095	.0086	.0063	34
35	.0095	.0090	.0078	.0056	35
36	.0090	.0075	.0070	.0050	36.

Part two.

A statement of the problem.

The widespread use of gasoline and its related products has created a demand for some device which would make the storage of these volatile liquids more safe, It has been thought by investigators that the wire screen placed in the vent pipe of storage tanks would prevent the passage of combustion into the tanks.

The problem is the Law of Cooling as applied to wire screens and to the pipe. The probability of flashing back is influenced by factors of the gas itself; namely, the ignition temperature of the gas, its calorific value, the specific heat of the gas and air, the specific heat of the products of combustion as well as the experimental factor.

The writer has confined his attention to the first named, hoping that he may be able to deduce a working equation.

The investigation was carried out using illuminating gas and brass wire screens.

Part Three.

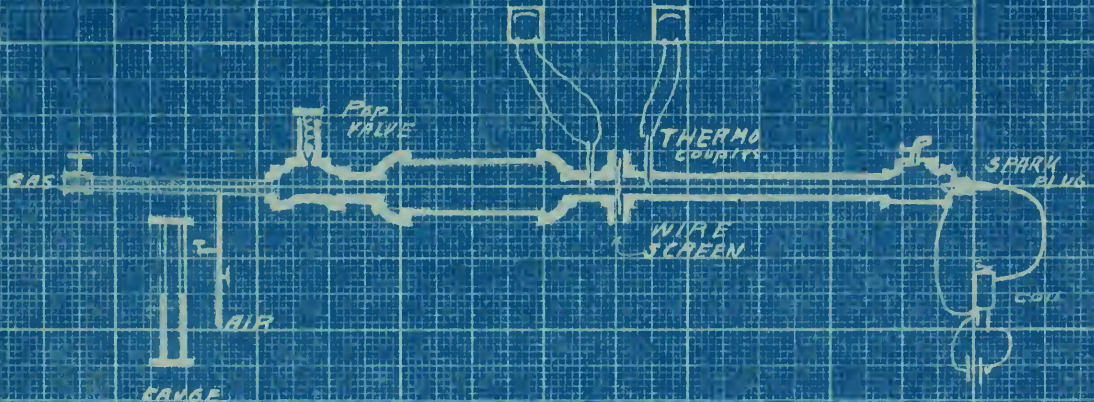
Description of Apparatus.

General.

The writer has endeavored in these experiments to reproduce the conditions under which devices of this nature are most likely to be used. Namely in standard pipe lines used as vents or fill pipes to storage tanks of volatile liquids.

The apparatus is briefly explained as follows: Two explosion chambers containing the same gas mixture, separated by a wire screen. The explosion originates in the one and passes to the other if screen employed is ineffective. A flame flashes back quicker in a still gas of uniform mixture than if flame were at end of tube, e.g. a burner.

The gas passing out of tube will have a different mixture than while in the tube. A screen placed here would easily prevent back fire. But in that cast it would not be known whether the gas mixture in the tube would support the flame. By placing both chambers in closed pipe line with wire screen insert between them a fair


GAS
AIR
RANGE
BAR VALVE
THERMO COUPLE
WIRE SCREEN
SPARK PLUG
COIL

test may be made. It would then be known that if a flame were detected in second chamber that the screen was ineffective.

Assuming that an explosion is the rapid passing of a flame wall thru a gas, the apparatus was designed to detect the presence of the flame on either side of the screen. A sensitive Thermocouple was employed. The apparatus consists of the following-named standard pipe fittings and special devices made or employed by the writer.

2 1-1/2" Tees.
1 1-1/2" Flange coupling.
2 3" - 1-1/2" Reducers.
1 3" Nipple 10" lg.
3 Pieces of 1-1/2" pipe.
Gas Connections.
Air Connections.
Spark Plug and Connections.
2 Thermo Couple Detectors.
2 Millivoltmeters.
Differential Gauge.
Screens to be Tested.

The flame originates at spark plug, passes down pipe line to detector and screen, then (?) past the other detector and into large chamber. The increase in pressure due to the rise in temperature and change of state of gas is relieved by a pop valve.

wrecking the same at every experiment.

Inserting screens. The chief difficulty of these tests is the getting of a tight connection where the screens were inserted. I had fair success in keeping pressure in system by the use of lead gaskets pressed into screen. Great care was needed not to distort the mesh by too great a pressure on gaskets.

The screens were inserted and the system tested for leaks. The differential gauge was used in testing for leaks, and also in measuring the pressure of gas when added to system.

Thermo-couple Detectors. The presence of the flame wall was detected by the use of two sensitive thermo-couple detectors. These couples were made by the writer. Each couple consisted of five junctions, three hot (inside the pipe) two cold (on the outside of pipe) the two free ends being connected to millivoltmeters. I used a No.26 Copper-Nickle (Advance wire) and a No. 25 Nickle-Iron wire. These were fused in

The electric arc. The sensitiveness of couples were tested by the holding of the couple in hand, which showed a wide deflection of needle. A match was dropped past ends of couples which gave a deflection. The blowing of the breath upon the couples caused a marked deflection. The writer feels certain that these couples would show without doubt the presence of any flame inside of system. These couples were placed in a 1/4" pipe in passing thru pipe wall, The space not occupied by the wire was filled with plaster paris. First pitch was tried but couples had to be rebuilt as it could not hold pressure in system.

The couples were placed two inches from the face of screen. This the writer feels sure would indicate the passage of flame through screen and then beyond it if there were a deflection of the galvanometer.

Relief Valve

The relief or pop valve as it is called is very simple in design and construction. The first tests were made using a U tube water trap. This the writer found gave a varying volume in system and gas mixtures could not be calculated. Then too it proved to be too sloppy to do satisfactory work.

The valve employed was made from brass. The valve consists of a conical valve seating into a valve seat and held closed by a spring. The compression of spring could be regulated by a knurled plug at top. The valve screwed into a one inch standard pipe bushing. By the placing of stronger springs inside barrel any relief pressure could be obtained.

The results obtained in experiments did not warrant the calibration of springs.

Part Four.

The tests. Data.

The method used in obtaining the mixtures of Gas-Air is as follows, assuming that gas and air are chemically inert.

V1 = Volume of system.
P1 = Pressure of V1 (Atmospheric pressure)
V2 = Volume of air in system subjected to pressure P2.
P2 = Pressure of gas supply.
V3 = V1 - V2 or gas supplied to system.

The temperature remaining constant.

Let the volume of system be V1 / P1 and at P2 the volume will be V2. Since the system is rigid there must be added a certain volume to make up the difference between V1 and V2. This volume is V3 or the amount of gas at the pressure of system. Since calculations are based upon the pressure of system at time of firing I will not correct for change in volume due to pressure of gas. The gas in this case being city gas.

The apparatus was first blown with compressed air and then closed at atmospheric pressure. The gas was then turned on getting five inches of water which equals .367 or .37

inch of Hg, since the value of the third Figure is not within the limits of the experiment. The atmospheric pressure was obtained from Weather Department in the Federal Building over the phone. This being the corrected pressure.

The gas-air mixture was allowed to diffuse about ten minutes, the gas supply being shut off as soon as readings were taken at beginning of experiment. The key to the electric circuit was then closed and the gas discharged. The deflections were noted almost simultaneously with the closing of the switch. The explosion sometimes did not take place but by waiting a few minutes and trying again it would be sure to follow.

The following gives the brass screens tested.

Mesh per inch.	No.Wire	Dec. size inches.	Size of opening.
16	26	.0205	.0420
18	27	.0187	.0368
20	28	.0165	.0335
22	29	.0155	.0300
24	30	.0137	.0280
30	31	.0122	.0211
40	33	.0102	.0148
50	35	.0090	.0110

The decimal sizes given in list are those taken from table of Clinton Wire Cloth Company, and were found to be correct within the limits of the experiments.

Data.

Screen M.	Screen W.	V2 P2	V3 %	Deflection of Galvanometer Face of screen.	Deflection of Galvanometer Back of screen.
16	26	199.5	2.6	*	*
16	26	29.24	1.28%	*	*
16	26	29.24	1.28%	*	*
18	27	29.24	1.28%	*	*
18	27	29.24	1.28%	*	*
18	27	29.24	1.28%	*	*
20	28	29.24	1.28%	*	*
20	28	29.24	1.28%	*	*
20	28	29.24	1.28%	*	*
22	29	29.24	1.28%	*	*
22	29	29.24	1.28%	*	*
22	29	29.24	1.28%	*	*

The Face of the screen was toward the spark plug.

Tests made on Feb. 10, 1916. Time, twelve hours

P1 = 28.9 cor. V1 = 202.1 cu. in.

*denotes deflection of needle of Galvanometer.

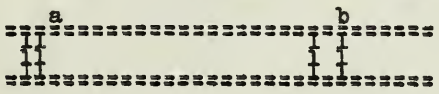
Gas pressure five inches of water or .346" Hg.

Part Five.

A Restatement of the Problem and a Discussion of the results.

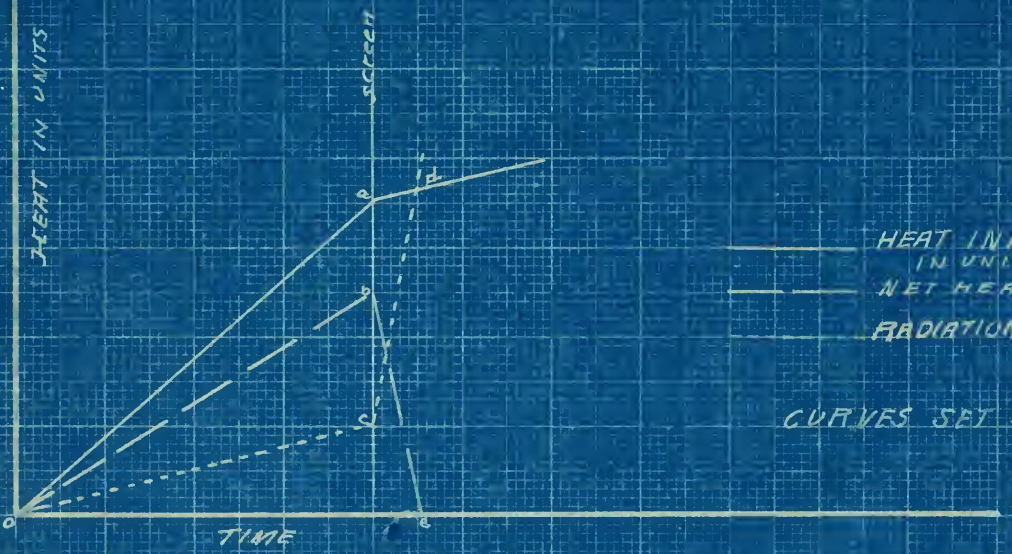
The effectiveness of the wire cloth depends upon its ability to conduct or abstract the heat from the flame wall as it passes thru the mesh of the screen.

Let us consider the flame starting at



"a". Here there are Xa heat units. Some of these heat units are conducted out thru pipe wall and some are needed to raise the next layer of gas to ignition point. Call this total heat loss as Ha. Now if Xa = Ha ignition will be impending if Xa is less than Ha it will not take place. If Xa is greater than Ha flame will propagate itself, the speed depending upon the excess heat. At this point the expansion factor of burnt gas will enter the expansion of burning gas will force flame wall before it and may cause the presence of unburnt gases which will

A STUDY OF THE RETARDATION OF COMBUSTION IN PASSING THRO WIRE SCREENS PLACED IN A CLOSED PIPE.



Part Five,

Resume.

Let H = Heat developed by the combustion of gas at any point. This will depend upon the calorific value of gas.

" Y = Heat necessary to raise the next layer of gas from temperature of container to that of ignition. This involves the specific heat of the gas and air.

" R = Heat losses due to conduction and radiation of pipe at this point. This would be influenced by the nature of the pipe and its temperature.

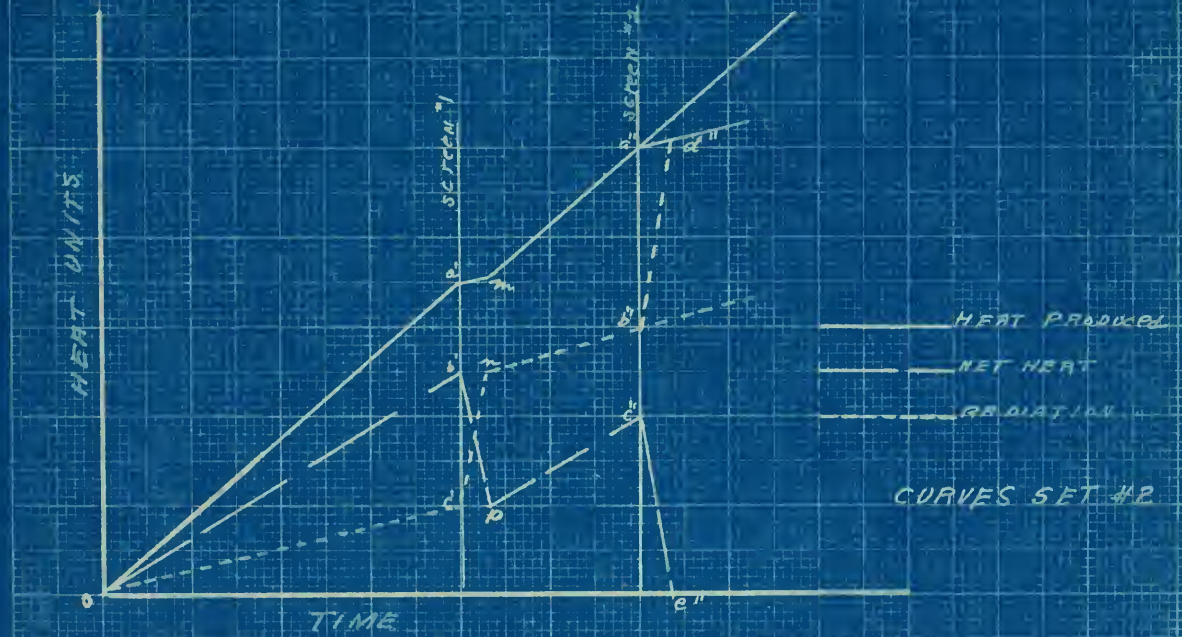
If H - R is greater than Y the flame will move along the pipe toward the screen. ------ (1)

If H - R=Y the flame will be impending -- (2)

If H - R is less than Y the flame will not pass on to the next layer of gas. ---------- (3)

The factors contained in terms H and Y are fairly well known to investigators for many gases. It is the factors contained in the term R that the writer has attempted to study.

In equation 2, two of the terms are fixed by the nature of the gas and part of the third term is fixed by the apparatus itself. It is


HEAT UNITS
TIME
SCREEN #1
SCREEN #2
HEAT PRODUCED
NET HEAT
RADIATION
CURVES SET #2

part of the term R that may be changed by the introduction of a wire screen into the pipe itself. The wire screen brings the gas into more intimate contact with metal, and thus aids conduction and increases the value of R. If a screen can be found that will increase this term so that equation 2 will become equation 3 the problem of the investigation has been solved. At the point where the flame would pass through the screen term H would be less than for the point just preceding due to the space occupied by the screen in the passage. This would increase the relative value of R in equation 2.

It would appear that to satisfy conditions that R equal Y to prevent passage of flame, if R has not equaled Y, (the presence of the flame being proof of that) there must be added to term H small increments of heat units from the preceding layers. The value of R then must be greater than Y + X_a; X_b; X_c;

etc. to satisfy the problem, where x_a; x_b; x_c; etc. are these small amounts of heat left from unsatisfied conditions preceding.

By means of curves the writer has attempted to show the relative value of wire screens as a method of taking up this extra heat and thus preventing the passage of flame in the pipe.

The solid line in the curves represents the amount of heat called H in the foregoing discussion, and the broken line the amount of heat left to supply the term Y. This may or may not be true but in the study of the curves the writer has assumed this to be true. The dotted line represents the factor R.

The break at a in curve o-a is the point at which the screen is reached. The slope of a-d is less than that of o-a due to the smaller amount of heat in the layer of gas at the screen. The steep curve c-d is the assumed property of the wire screen in increasing the radiation factor R. The fall of curve b-e represents

the amount of heat left to meet factor Y. If this crosses the X axis the flame will not pass through the wire screen. Since radiation involves time, the cooling of the gas must be done in less time than the flame propagates itself while passing through the screen.

In the second set of curves the same conditions were assumed with the exception that the flame did pass through the screen. A second screen was set in the path to cool the flame below its ignition point.

It is the opinion of the writer that it is possible to obtain these curves by experiment. He has found that a great amount of preliminary experimental work must be done before arriving at any satisfactory conclusions, as to the action of screens when placed in pipes for the above purpose. This preliminary work would involve the study of the explosive limits of a gas-air mixture and the speed at which it would take place; the effect of temperature upon the speed if mixture is in a closed space; and the radiation factors of the container and screen

at temperatures of the experiment.

The results obtained in these experiments seem to be at variance with the explosive limits of gas-air mixtures as obtained by other investigators. It is the opinion of the writer that it would be more satisfactory to have mixture in large reservoir and use it from there and not make mixture each time. The chemical analysis of the vapor before and after explosion would determine and check the fact that complete combustion had taken place.